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(54) SECURE AND OPAQUE TYPE LIBRARY PROVIDING SECURE DATA PROTECTION OF VARIABLES

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G06F 11/30	(2006.01)
G06F 12/14	(2006.01)
H04L 9/32	(2006.01)

(52) **U.S. Cl.** **707/104**; 707/1; 713/190; 713/194

(58) **Field of Classification Search** 707/104, 707/1; 713/194, 190
See application file for complete search history.

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(57) ABSTRACT

A method, apparatus, and article of manufacture for providing secure and opaque type libraries to automatically provide secure variables within a programming module. A system for providing secure and opaque type libraries to automatically provide secure variables within a programming module. The system includes an OTL selection module, an OTL substitution module, an OTL type library database, a compiler module; and a linker module to create an executable processing module. The OTL selection module randomly selects or generates one of the possible variable obfuscation functions for each declared secure variable. The OTL substitution module substitutes the separate instance of the selected variable obfuscation function for every reference to the declared secure variable. The OTL type library database receives queries from the OTL selection module a database to identify of possible variable obfuscation functions applicable for the variable type corresponding to the declared secure variables.

28 Claims, 10 Drawing Sheets

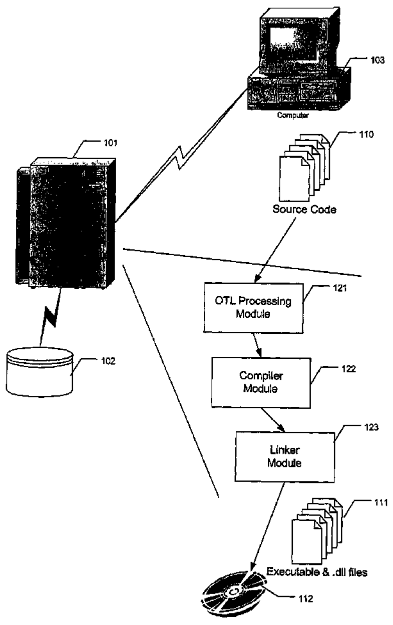


FIG. 1

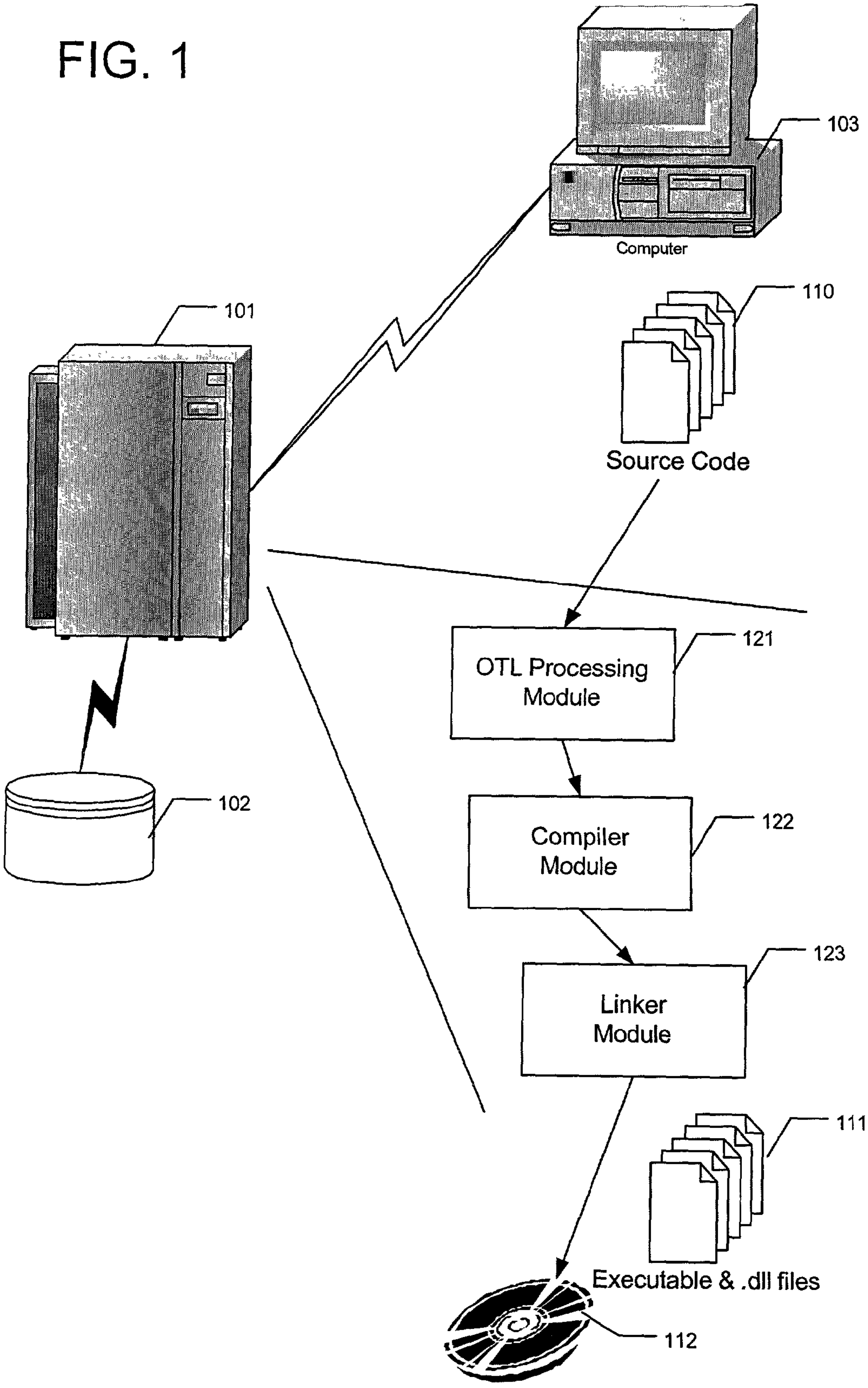

103
Computer
110
Source Code
101
OTL Processing Module
121
Compiler Module
122
102
Linker Module
123
111
Executable & .dll files
112

Fig. 2

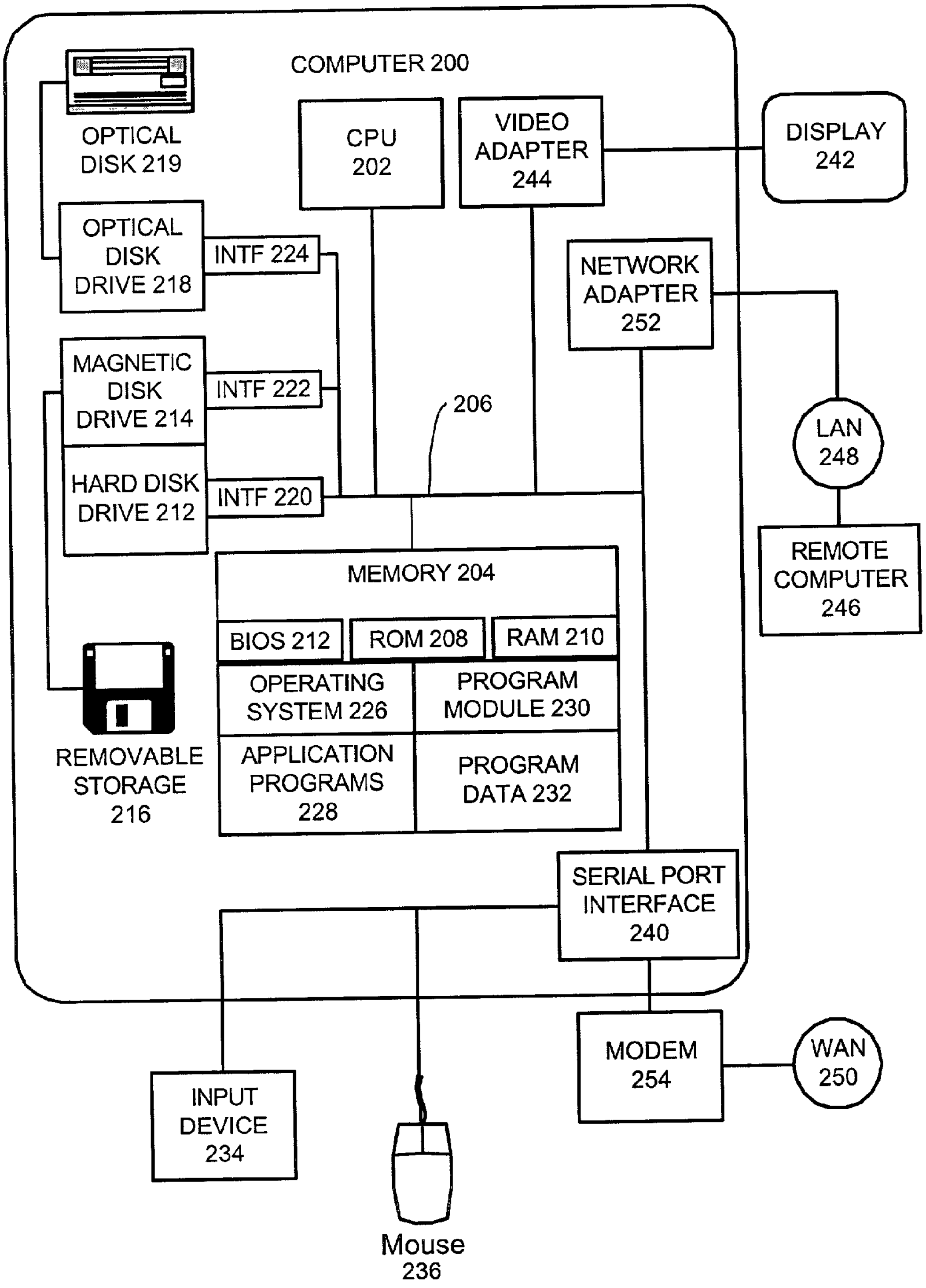

COMPUTER 200
OPTICAL DISK 219
OPTICAL DISK DRIVE 218
INTF 224
CPU 202
VIDEO ADAPTER 244
DISPLAY 242
NETWORK ADAPTER 252
MAGNETIC DISK DRIVE 214
INTF 222
206
LAN 248
HARD DISK DRIVE 212
INTF 220
REMOTE COMPUTER 246
MEMORY 204
BIOS 212
ROM 208
RAM 210
OPERATING SYSTEM 226
PROGRAM MODULE 230
APPLICATION PROGRAMS 228
PROGRAM DATA 232
REMOVABLE STORAGE 216
SERIAL PORT INTERFACE 240
MODEM 254
WAN 250
INPUT DEVICE 234
Mouse 236

Fig. 3

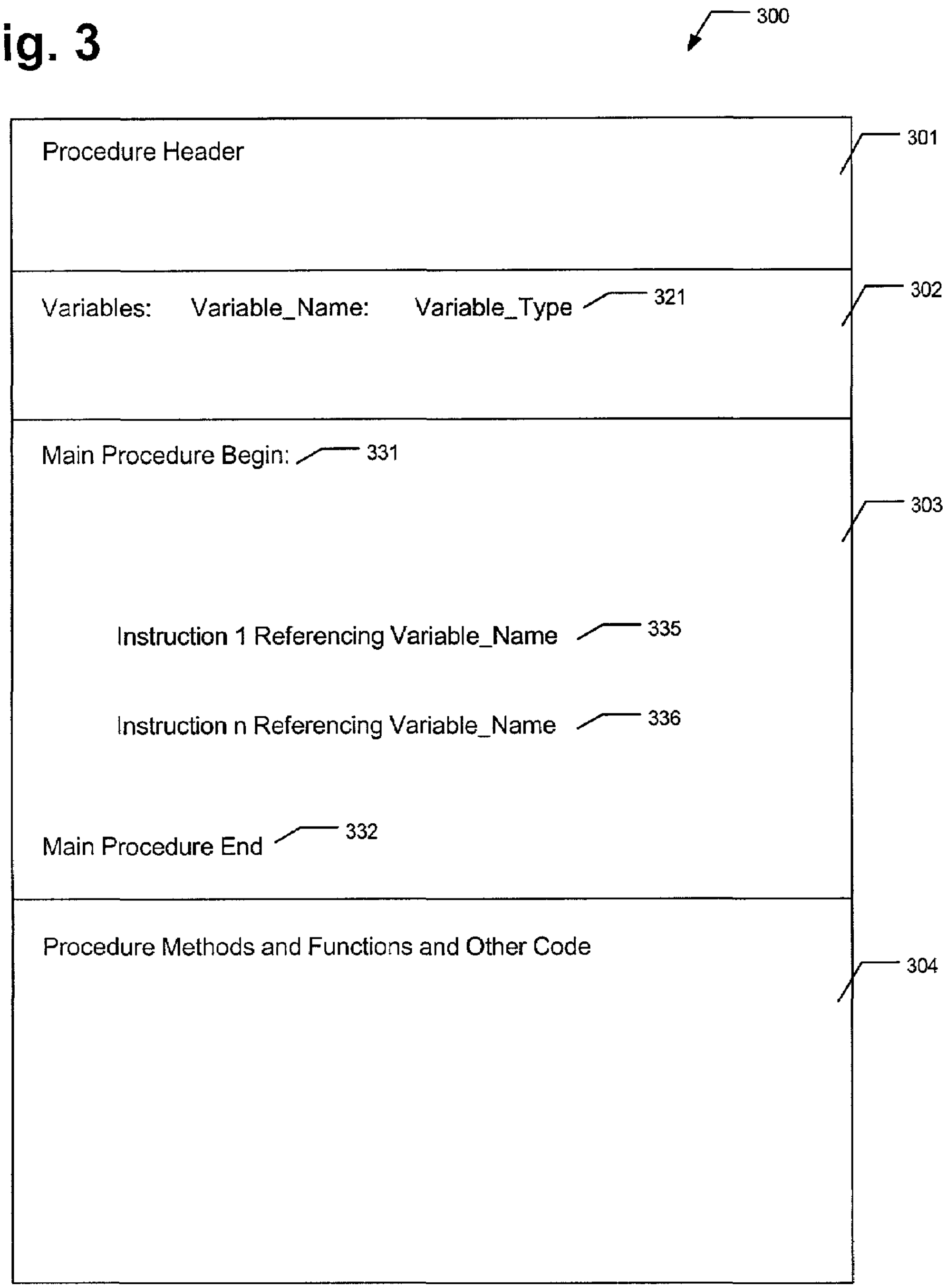
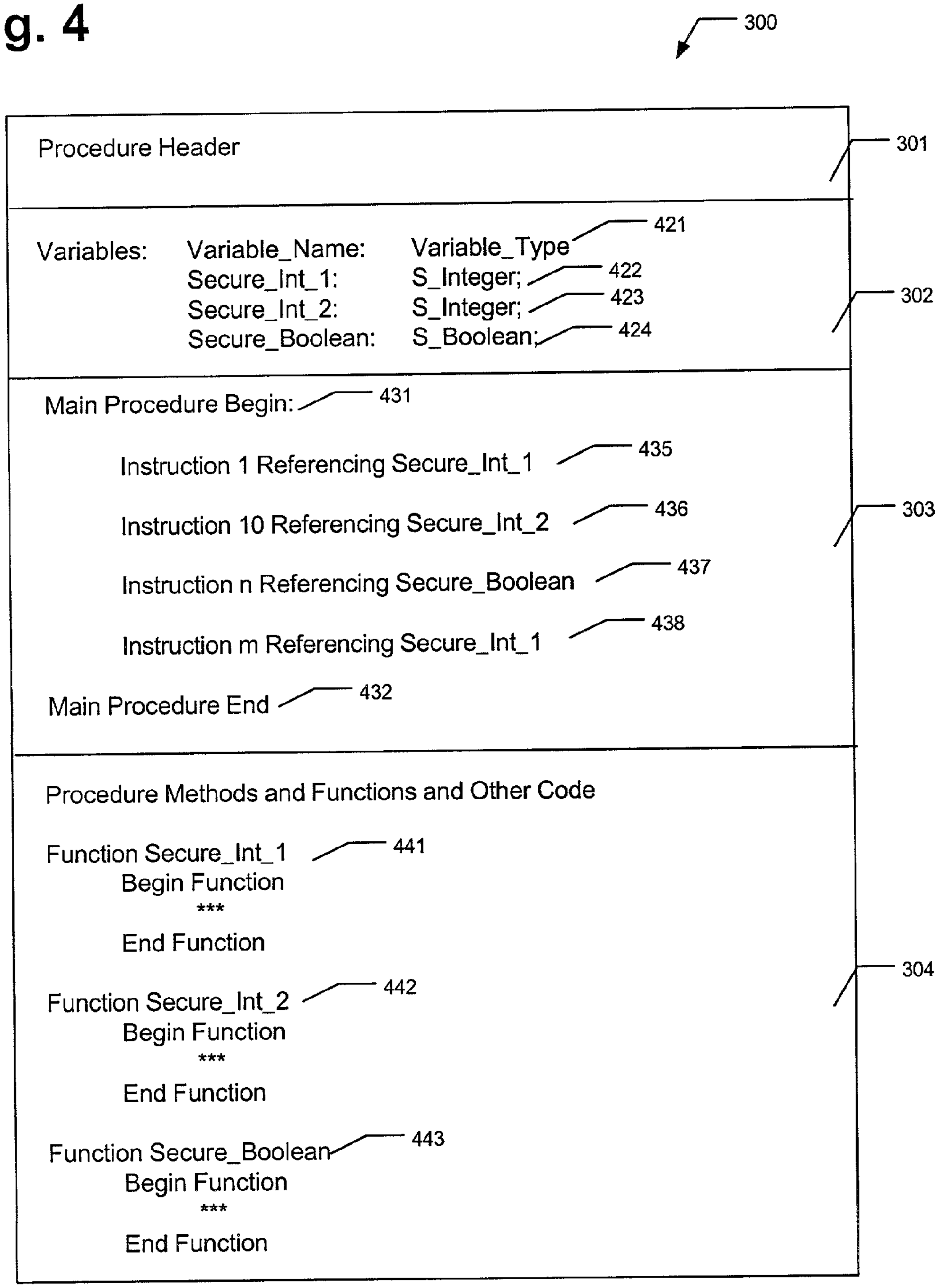
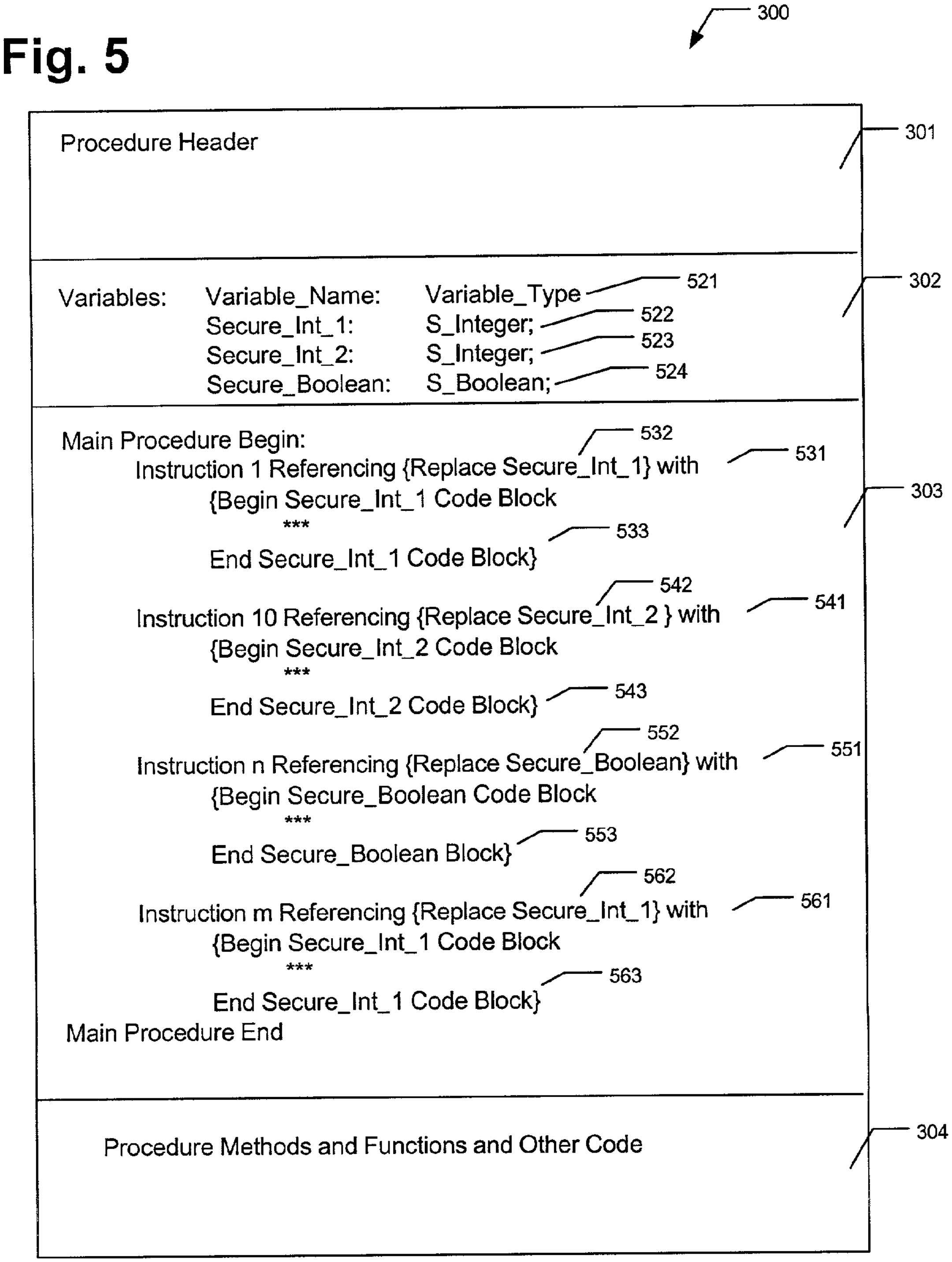

300
Procedure Header
301
Variables: Variable_Name: Variable_Type
321
302
Main Procedure Begin:
331
303
Instruction 1 Referencing Variable_Name
335
Instruction n Referencing Variable_Name
336
Main Procedure End
332
Procedure Methods and Functions and Other Code
304

Fig. 4



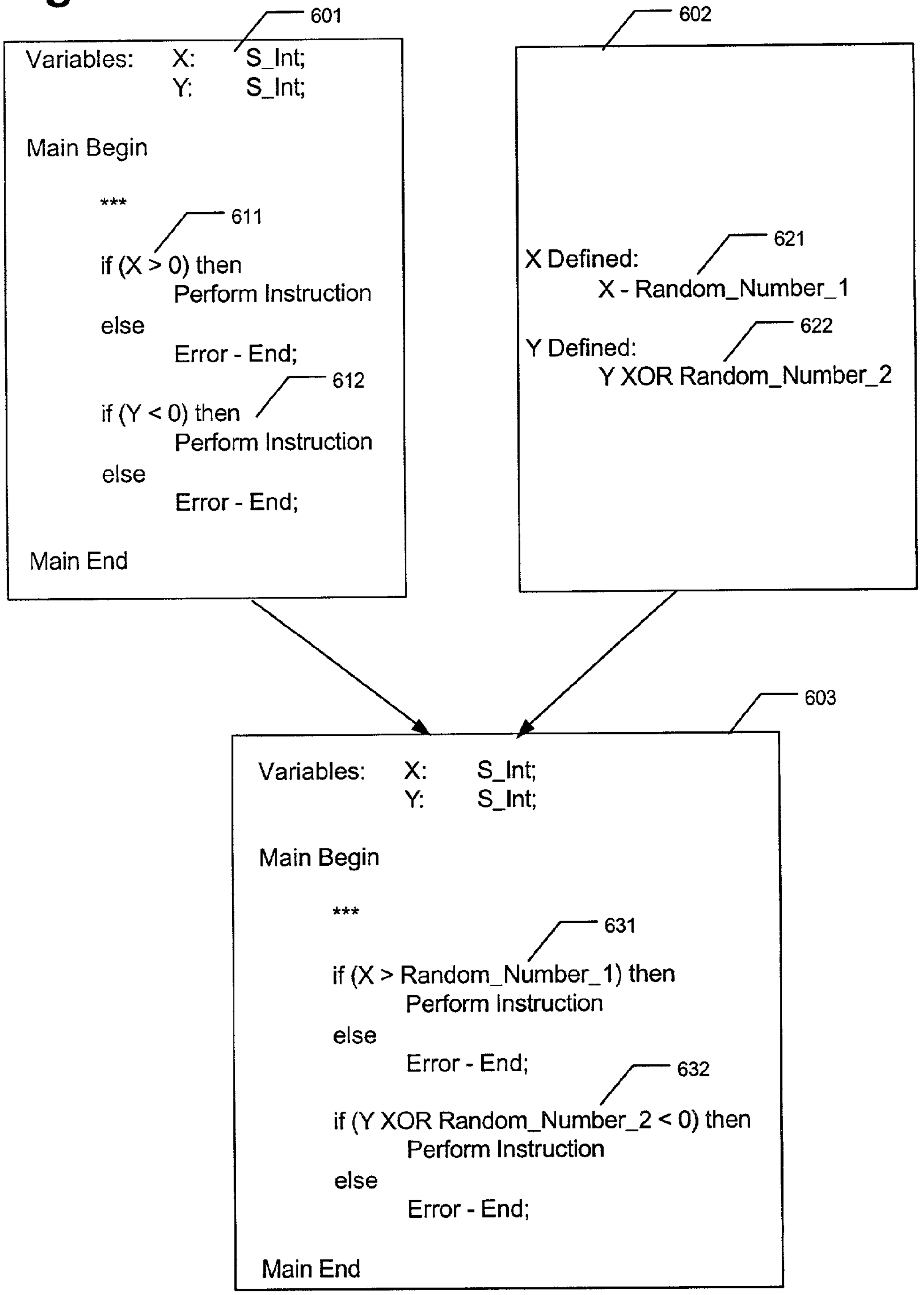
```
Procedure Header

Variables:    Variable_Name:      Variable_Type
              Secure_Int_1:       S_Integer;
              Secure_Int_2:       S_Integer;
              Secure_Boolean:     S_Boolean;

Main Procedure Begin:

        Instruction 1 Referencing Secure_Int_1

        Instruction 10 Referencing Secure_Int_2

        Instruction n Referencing Secure_Boolean

        Instruction m Referencing Secure_Int_1

Main Procedure End

Procedure Methods and Functions and Other Code

Function Secure_Int_1
        Begin Function
            ***
        End Function

Function Secure_Int_2
        Begin Function
            ***
        End Function

Function Secure_Boolean
        Begin Function
            ***
        End Function
```

Fig. 5



```
Procedure Header

Variables:   Variable_Name:      Variable_Type
             Secure_Int_1:       S_Integer;
             Secure_Int_2:       S_Integer;
             Secure_Boolean:     S_Boolean;

Main Procedure Begin:
     Instruction 1 Referencing {Replace Secure_Int_1} with
          {Begin Secure_Int_1 Code Block
                ***
          End Secure_Int_1 Code Block}
     Instruction 10 Referencing {Replace Secure_Int_2 } with
          {Begin Secure_Int_2 Code Block
                ***
          End Secure_Int_2 Code Block}
     Instruction n Referencing {Replace Secure_Boolean} with
          {Begin Secure_Boolean Code Block
                ***
          End Secure_Boolean Block}
     Instruction m Referencing {Replace Secure_Int_1} with
          {Begin Secure_Int_1 Code Block
                ***
          End Secure_Int_1 Code Block}
Main Procedure End

     Procedure Methods and Functions and Other Code
```

Fig. 6



```
Variables:    X:     S_Int;
              Y:     S_Int;

Main Begin

        ***

        if (X > 0) then
                Perform Instruction
        else
                Error - End;
        if (Y < 0) then
                Perform Instruction
        else
                Error - End;

Main End
```

```
X Defined:
        X - Random_Number_1

Y Defined:
        Y XOR Random_Number_2
```

```
Variables:    X:     S_Int;
              Y:     S_Int;

Main Begin

        ***

        if (X > Random_Number_1) then
                Perform Instruction
        else
                Error - End;
        if (Y XOR Random_Number_2 < 0) then
                Perform Instruction
        else
                Error - End;

Main End
```

Fig. 7

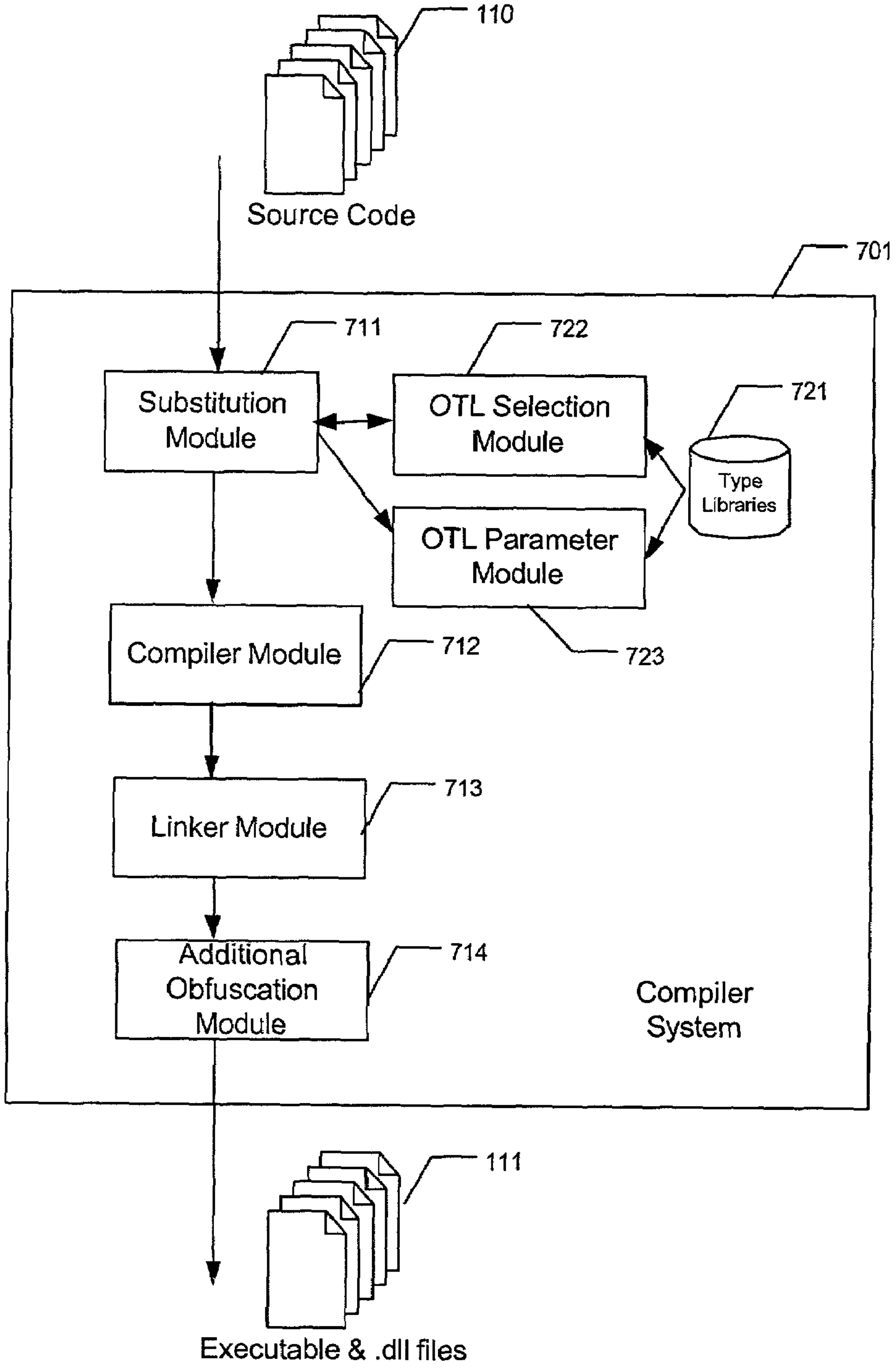

110
Source Code
701
711
Substitution Module
722
OTL Selection Module
721
Type Libraries
OTL Parameter Module
723
Compiler Module
712
Linker Module
713
Additional Obfuscation Module
714
Compiler System
111
Executable & .dll files

Fig. 8a

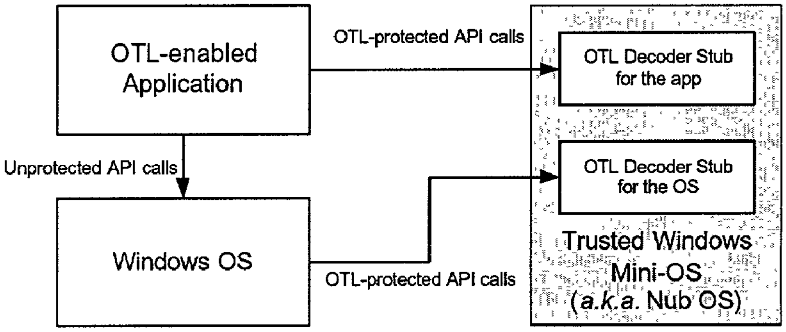

OTL-enabled Application
OTL-protected API calls
OTL Decoder Stub for the app
Unprotected API calls
OTL Decoder Stub for the OS
Windows OS
OTL-protected API calls
Trusted Windows Mini-OS (*a.k.a.* Nub OS)

Fig. 8b

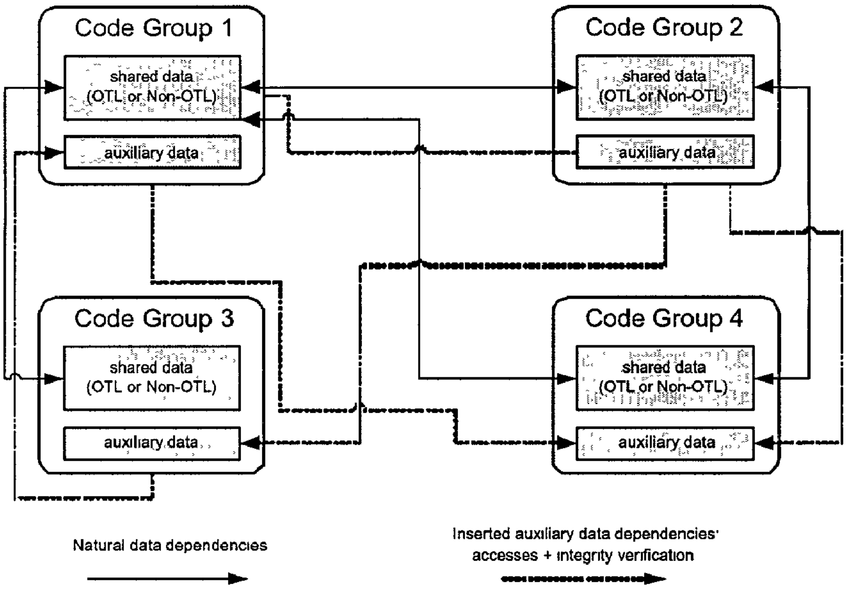
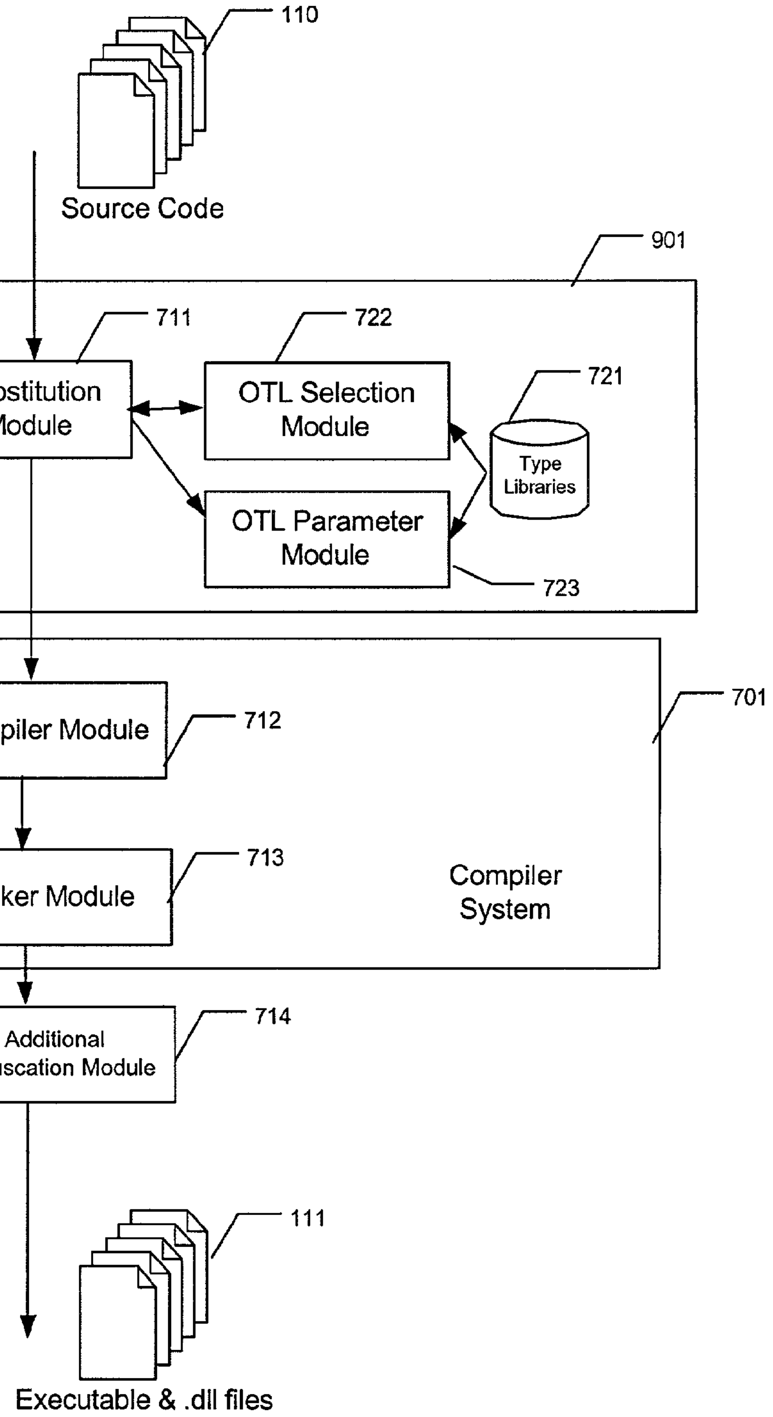

Code Group 1
shared data (OTL or Non-OTL)
auxiliary data
Code Group 2
shared data (OTL or Non-OTL)
auxiliary data
Code Group 3
shared data (OTL or Non-OTL)
auxiliary data
Code Group 4
shared data (OTL or Non-OTL)
auxiliary data
Natural data dependencies
Inserted auxiliary data dependencies: accesses + integrity verification

Fig. 9


110
Source Code
901
711
Substitution Module
722
OTL Selection Module
721
Type Libraries
OTL Parameter Module
723
Compiler Module
712
701
Linker Module
713
Compiler System
Additional Obfuscation Module
714
111
Executable & .dll files

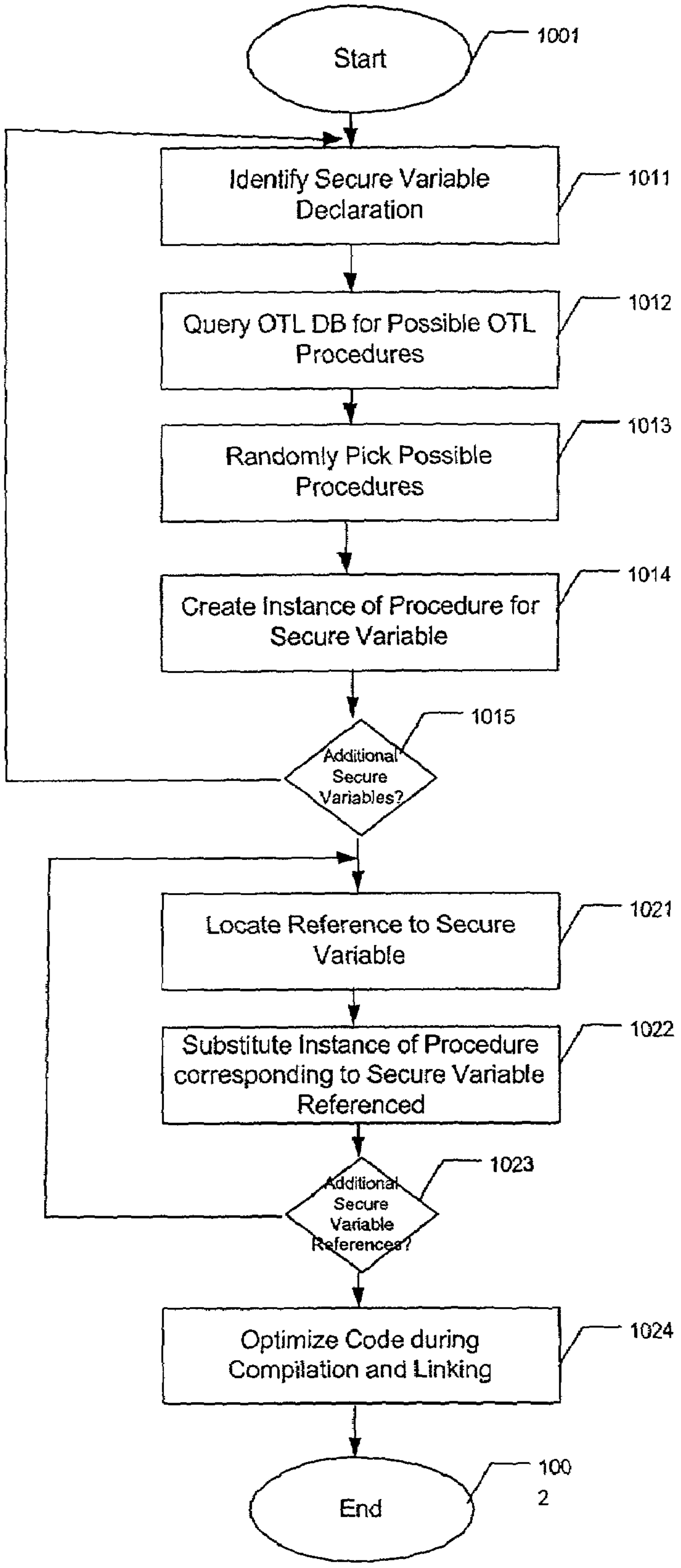

Start
1001
Identify Secure Variable Declaration
1011
Query OTL DB for Possible OTL Procedures
1012
Randomly Pick Possible Procedures
1013
Create Instance of Procedure for Secure Variable
1014
Additional Secure Variables?
1015
Locate Reference to Secure Variable
1021
Substitute Instance of Procedure corresponding to Secure Variable Referenced
1022
Additional Secure Variable References?
1023
Optimize Code during Compilation and Linking
1024
End
100
2

Fig. 10

SECURE AND OPAQUE TYPE LIBRARY PROVIDING SECURE DATA PROTECTION OF VARIABLES

TECHNICAL FIELD

The invention relates generally to a system, method and article of manufacture to provide secure variables within programming modules and more particularly to a system, method and article of manufacture for providing secure and opaque type libraries to automatically provide secure variables within a programming module.

BACKGROUND

Ever since the days of early IBM PCs and 8-bit machines, application programmers and crackers have fought a never-ending battle in the field of software protection. Creating "uncrackable" programs remains a theoretical and practical open problem, especially against skilled and talented reverse engineers who devote significant amounts of time and effort to their job. However, various techniques of obfuscation and tamper resistance can be useful depending on the models of piracy in given channels, to deter casual pirates or delay crackers who attempt to bypass security checks, attach viruses, patch code and data at runtime, and in general alter software behavior.

Developers have often treated software security as an independent feature that can be easily "plugged in" once an application is finished. Indeed, a large number of automatic "protectors" or "wrappers" are available to encrypt executables and add layers of anti-hacking code. Unfortunately, such plug-in solutions have typically proven quite breakable and ineffective, despite continuing upgrades and improvements to address hacks that appear within days or even hours. In a certain theoretical models, automatic obfuscation of programs is not possible. All this provides some evidence that programmers wishing to create secure software need to be involved more deeply with protection.

Programmers need to involve themselves in the protection process from the beginning. A programmer needs to flag which variables and computations thereof that need be protected and indicate, whenever possible, degree of protection sought in some manner. The compiler then may pool these flagged portions with some variables it generates, obfuscates and verifies common data types and operation. One of the goals is to make the accesses to the data types leak very little information unless the attacker observes for a significant amount of time across many local sections of the code as it executes. Tampering a variable without proper information will lead to inconsistent or incorrect data or results. The user may also flag variables (e.g. a return address) as to be tamper evident when it will be appended with a randomized check sum akin to a cryptographic check sum; this if tampered with high probability it will be detected. OTL both provides protection tools and makes the programmer pay special attention to security-critical code. Additionally, OTL can inject "useless" data and code, both to disguise crucial data and to deflect the cracker's attention away from sensitive data and code; such "useless" data and code can be tightly interleaved with the rest of the application, including OTL-protected parts. To maximize security, OTL can be combined with other techniques we implemented, such as oblivious hashing, code-integrity checks, piecewise code encryption, anti-debugging, and others.

Software obfuscation is a widely-used method for software vendors to thwart illegitimate attempts at reverse

engineering their products. Past efforts have focused mostly on code obfuscation, with data left largely in the clear. The tools available for hiding and protecting critical data invariably follow the decrypt-use-encrypt paradigm, and are generally used manually or semi-automatically by developers after the software is written. The following example, Sample 1 shows an example of using such a system. It shows a piece of code that manages a free-trial period. Every time this code is invoked, it checks a global variable iTimeLeft; if its value is zero, the code will ask the user to register the software.

SAMPLE 1

A simple sample code to manage free-trial period.

```
extern int32                iTimeLeft;
bool                        bTimeToRegister;
bTimeToRegister = iTimeLeft < 0;
if (bTimeToRegister) {
    // ask the user to register
}
iTimeLeft - - -;
```

Sample 2 shows the changes from applying a typical decrypt-use-encrypt method. First, the key variable, iTimeLeft, is stored in its encrypted (and expanded) form as a 64-bit integer. A macro is used to decrypt the 64-bit data into 32-bit clear text. The clear-text time counter is then checked and decremented before it is re-encrypted and stored away.

SAMPLE 2

The traditional decrypt-use-encrypt approach.

```
extern int64                iTimeLeft;
int32                       iTemp;
bool                        bTimeToRegister;
iTemp = DECRYPT_AND_CHECK_MAC_INT32
(iTimeLeft, MY_KEY) ;
bTimeToRegister = iTimeLeft < 0;
if (bTimeToRegister) {
    // ask the user to register
}
iTimeLeft - - -;
```

The decrypt-use-encrypt approach has two weaknesses. First, the protected variables appear in plaintext between the decryption and encryption stages. An attacker can discover what the program is doing by setting appropriate breakpoints and checking register contents. Though DRM systems often employ some form of anti-debugging, such measures historically have been easy tnot so hard to defeat; also, powerful debuggers, simulators, and in-circuit emulators can render the entire system at the attacker's disposal.

Second, data security tends to be applied as an afterthought; the developers explicitly insert macros or library function calls. There is no guarantee that accesses to secure data are always bracketed by decryption and encryption macros. As a matter of fact, bugs have arisen because developers forgot to apply decryption macros before manipulating the secure data. Due to its manual nature, decrypt-use-encrypt processing is applied to only a few key variables in a program.

A systematic approach is needed to data hiding and protection, which can meet the following criteria:

A non-intrusive methodology for annotating the software during its development cycle so that it can be adopted easily by developers and employed efficiently. The underlying mechanisms & algorithms of supporting the indicated protection can be developed independently in a modular way and made available for use as a programming language tools and transformations (e.g. compilers.)

Protected data objects are seldom manipulated in clear-text form.

Breaking data protection for one data object does not lead to cracking of other protected objects.

There are no automated tools to reverse engineer our data protection mechanisms. In particular traditional program flow analysis tools should not be able to discover the details of the exact protection mechanism used in a given copy of the protected application. The attacker has to work through the entire program laboriously (many times) to uncover the original data objects.

Oblivious (i.e., unobvious and well-disguised) comparison of data (e.g. Is A=B?) and oblivious return of results (e.g. If A=B return the result in a probabilistic fashion in a variable C; if C does not have the right properties it will corrupt some protected data variable and lead to incorrect operation).

SUMMARY

The present invention relates to a method, apparatus, and article of manufacture to provide secure variables within programming modules and more particularly to a system, method and article of manufacture for providing secure and opaque type libraries to automatically provide secure variables within a programming module.

One aspect of the present invention is a system for providing secure and opaque type libraries to automatically provide secure variables within a programming module. The system includes an OTL selection module, an OTL substitution module, an OTL type library database, a compiler module; and a linker module to create an executable processing module. The OTL selection module randomly selects or generates one of the possible variable obfuscation functions for each declared secure variable. The OTL substitution module substitutes the separate instance of the selected variable obfuscation function for every reference to the declared secure variable. The OTL type library database receives queries from the OTL selection module a database to identify possible variable obfuscation functions applicable for the variable type corresponding to the declared secure variables.

Another aspect of the present invention is a method, and corresponding computer data product for providing secure and opaque type libraries to automatically provide secure variables within a programming module. The method identifies secure variable declaration statements within a source code module, queries a database for identification of possible variable obfuscation functions applicable for the variable type corresponding to the secure variable declaration statement, randomly selects or generates one of the possible variable obfuscation functions returned in response to the database query, creates a separate instance of the selected variable obfuscation function corresponding to the secure variable declaration, and substitutes the separate instance of the selected variable obfuscation function for every reference to the declared secure variable. The variable declaration statement comprises a variable type declaration used to select the variable obfuscation function.

These and various other advantages and features of novelty which characterize the invention are pointed out with particularity in the claims annexed hereto and form a part hereof. However, for a better understanding of the invention, its advantages, and the objects obtained by its use, reference should be made to the drawings which form a further part hereof, and to accompanying descriptive matter, in which there are illustrated and described specific examples of an apparatus in accordance with the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a computing system to create secure variables using Opaque Type Libraries according to one embodiment of the present invention.

FIG. **2** illustrates an exemplary computing system that may be used to support various computing system that are part of example embodiments of the present invention.

FIG. **3** illustrates a block diagram for a program module using OTL variables according to an embodiment of the present invention.

FIG. **4** illustrates a block diagram for a program module using OTL variables calling procedures according to an embodiment of the present invention.

FIG. **5** illustrates a block diagram for a program module using OTL variables in which OTL procedures are substituted into the programming module according to an embodiment of the present invention.

FIG. **6** illustrates a block diagram for a program module using OTL variables in which OTL procedures are substituted into the secure variable references according to an embodiment of the present invention.

FIG. **7** illustrates a processing system for generating executable program modules using OTL modules according to one possible embodiment of the present invention.

FIGS. **8***a* and *b* Illustrate additional obfuscation processing that may be included within an OTL process according to yet another example embodiment of the present invention.

FIG. **9** illustrates a processing system for generating executable program modules using OTL modules according to another possible embodiment of the present invention.

FIG. **10** illustrates an operational flow for generating executable program modules using OTL modules according to yet another example embodiment of the present invention.

DETAILED DESCRIPTION

The present invention relates to a system, method and article of manufacture for providing secure and opaque type libraries to automatically provide secure variables within a programming module.

FIG. **1** illustrates a computing system to create secure variables using Opaque Type Libraries (OTL) according to one embodiment of the present invention. An OTL is a collection of data types (e.g., C++ classes). Each data type directs the compiler to generate an individualized implementation for each protected data object. One can loosely think of OTL as MFC for data security. By using OTL, the developers conveniently specify which data objects to protect during the design and coding stages. This seemingly simple step has the immediate benefit of involving the developers in thinking about data protection from Day One of software design. This simple step is illustrated by the following example, Sample 3. It shows how the trial period test code is easily transformed: The developer needed only to change the type declaration for iTimeLeft from int32 to SInt32. In addition, the result of testing iTimeLeft is assigned to a secure Boolean bTimeToRegister. The use of a secure Boolean variable in the IF statement instructs the compiler to obfuscate and protect the branch.

SAMPLE 3

The OTL approach to data protection and obfuscation.

```
extern SInt32                iTimeLeft;
SBool                        bTimeToRegister;
bTimeToRegister = iTimeLeft <= 0;
if (bTimeToRegister) {
    // fire up the registration stuff
. . .
}
```

The bulk of the OTL system resides in or used by the compiler (or OTL backend). It can be plugged into the compilation pipeline to transform the intermediate representation or byte code. Its main task is to generate individualized representations and implementations for OTL objects. This is achieved by developing a library of meta-implementations of OTL data types that can be parameterized to yield diverse-looking implementations of OTL objects. For example, an integer with a small range can be implemented using homomorphism, graph properties, and bit count in a vector. If the OTL backend chooses homomorphisms as a meta-implementation, it still has the freedom to choose the exact homomorphism from a set of many, using a random key. In general, integer-value properties about any data structures can be used to represent integers. Data encryption can simply be done with homomorphism, in which addition and subtraction take the form of multiplication and division, respectively.

The meta-implementations in the OTL backend allow manipulation of protected objects in their obfuscated form. For example, a meta-implementation of the OTL character string simply encrypts the string using a symmetric cipher. In order to append another OTL string to this one, it is necessary only to change the encryption of the other string, character-by-character in an arbitrary order.

In one embodiment, OTL utilizes a library of secure 32-bit and 64-bit integers with addition, multiplication, and comparison operations, secure strings with concatenation and character search operations, and secure Booleans. The compiler analysis of operations used on a given OTL variable is crucial for achieving strong protection. For example, blindly applying Homomorphic Encryption to protect OTL integers is insufficient to hide the true value of the data. If multiplication, addition, subtraction, and comparison operators are provided, the attacker can use binary search to figure out a true value of an OTL integer. However this may not be possible to efficiently carry out this attack, if no comparison operator is given. Thus supporting a full set of operations needs care and switching between different types of homomorphisms in a hidden manner. Therefore, some sophistication is required to generate obfuscated and individualized operators that are tailored to each protected variable. For example, only addition operators are generated for offset variables, increment and test-for-equality operators for the loop counters, etc.

A salient feature of OTL is complete obfuscation of operations on protected data. In the above example, the comparison operator (<=) and the decrement operator (—) on the SInt32 variable iTimeLeft work directly in the obfuscated domain. In addition, the result of the comparison operator will be represented as an obfuscated Boolean value, for which many values map to True and many others map to False. Representations of Booleans can vary with time and program state (a.k.a. Time-Varying OTL), so that a value representing True at one point may represent False later, and vice versa. Original, plaintext data values never or seldom appear in the program's execution.

An important application of Time-Varying OTL is authenticated function call. In this model, a function can be annotated as call-by-authentication; parameters passed to this function, as well as the return value, are protected using Time-Varying OTL, which varies from machine to machine and from time to time. A virus that is injected into a remote client machine will have no easy way to figure out the encoding scheme used at the time and hence is prevented from using OTL-protected internal functions to cause damages.

The partition of our OTL system into a relatively static type interface and compile-time instantiation stage offers two benefits. First, the developers can work with a stable interface and worry less about keeping up with upgrades. Second, the OTL compiler component is free to choose (using a random key) whichever meta-implementation is available for a given OTL type and individualize the type instantiation on a per-object basis.

OTL is a language-level concept. OTL is platform independent, whereas most software protection tools to-date are tied to a particular machine platform. Unlike existing software protection tools, type safety in an OTL-enabled program is automatically guaranteed by the compiler; thus, many program bugs can be avoided. (We should point out that with explicit decrypt-encrypt macros, one can also build a data-flow analysis tool to enforce the decrypt-use-encrypt rule. Such a tool, however, is unavailable as of yet.)

OTL is tightly integrated into the programming environment either through a rich class hierarchy in the model of MFC and ATL, or by augmented C/C++/C# languages and compilers. It is relatively straightforward for developers to specify variables and static constants that need be protected. A compile-time switch (or macro definition) enables/disables OTL. This allows the same program to be compiled with or without data obfuscation, making it easier to debug the application code.

Data obfuscation alone is typically insufficient to protect software. Very often, our ultimate goal is to forestall illegitimate tampering of the software either by pirates or by agents trying to attack the security of computer systems by exploiting loopholes to access and modify data (e.g return addresses) to usurp control of the system and its resources. Tampering often takes one of two forms (or both): patching the software binary and altering the data. Data obfuscation makes it difficult for the attacker to guess the proper values for OTL-protected data objects within the program. Furthermore, each OTL object has built-in mechanism for integrity verification, which makes it even harder for the attacker to alter data: even if the attacker knows how to exactly to modify a given variable to effect his attack, he or she may not know how to exactly represent it without suitable keys.

Unable to patch program data, the attacker may attempt to patch the binary to remove some critical code from the execution path. Since current instruction set architectures use binary conditions to trigger branches, an OTL Boolean object will eventually be resolved into a single bit to be used by machine code. This will be an attractive place for the attacker to alter the machine registers to bypass a critical code segment. Although code-integrity verification and Oblivious Hashing are effective ways to detect and thwart such attacks, our OTL system can offer additional and new ways of protection in conjunction with these methods. For example, OTL offers a good way of hiding the variables in a way that it is not clear that they are being protected. Another issue is that one can automatically generate a number of homomorphic encryption schemes and switch between them as needed in a hidden fashion. For example, one may employ one-time-pad encryptions during comparison and use encryptions based on addition and multiplication for checking for equality and switch between the two; One may use a program analysis tool one can automatically effect this. A number of homomorphic encryption systems have been conceived in the cryptographic literature but here we do not necessarily need such ciphers of high strength. It is known how (by carefully composing elementary arithmetic operations with random constants) to generate authentication tag generation mechanisms (reversible and non reversible) randomly and they may be used here to automatically choose encryption and authentication mechanisms. One of our ideas is to transform an OTL Boolean object that serves as a branch condition into a number of objects, which are further checked by code in both targets of the branch. There are exponential number of ways to obfuscate a Boolean variable and branch conditions. OTL allows compiler-time individualization of branch protection that is transparent to developers.

With reference to FIG. **2**, an exemplary computing system for embodiments of the invention includes a general purpose computing device in the form of a conventional computer system **200**, including a processor unit **202**, a system memory **204**, and a system bus **206** that couples various system components including the system memory **204** to the processor unit **200**. The system bus **206** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus and a local bus using any of a variety of bus architectures. The system memory includes read only memory (ROM) **208** and random access memory (RAM) **210**. A basic input/output system **212** (BIOS), which contains basic routines that help transfer information between elements within the computer system **200**, is stored in ROM **208**.

The computer system **200** further includes a hard disk drive **212** for reading from and writing to a hard disk, a magnetic disk drive **214** for reading from or writing to a removable magnetic disk **216**, and an optical disk drive **218** for reading from or writing to a removable optical disk **219** such as a CD ROM, DVD, or other optical media. The hard disk drive **212**, magnetic disk drive **214**, and optical disk drive **218** are connected to the system bus **206** by a hard disk drive interface **220**, a magnetic disk drive interface **222**, and an optical drive interface **224**, respectively. The drives and their associated computer-readable media provide nonvolatile storage of computer readable instructions, data structures, programs, and other data for the computer system **200**.

Although the exemplary environment described herein employs a hard disk, a removable magnetic disk **216**, and a removable optical disk **219**, other types of computer-readable media capable of storing data can be used in the exemplary system. Examples of these other types of computer-readable mediums that can be used in the exemplary operating environment include magnetic cassettes, flash memory cards, digital video disks, Bernoulli cartridges, random access memories (RAMs), and read only memories (ROMs).

A number of program modules may be stored on the hard disk, magnetic disk **216**, optical disk **219**, ROM **208** or RAM **210**, including an operating system **226**, one or more application programs **228**, other program modules **230**, and program data **232**. A user may enter commands and information into the computer system **300** through input devices such as a keyboard **234** and mouse **236** or other pointing device. Examples of other input devices may include a microphone, joystick, game pad, satellite dish, and scanner. For hand-held devices and tablet PC devices, electronic pen input devices may also be used. These and other input devices are often connected to the processing unit **202** through a serial port interface **240** that is coupled to the system bus **206**. Nevertheless, these input devices also may be connected by other interfaces, such as a parallel port, game port, or a universal serial bus (USB). A monitor **242** or other type of display device is also connected to the system bus **206** via an interface, such as a video adapter **244**. In addition to the monitor **242**, computer systems typically include other peripheral output devices (not shown), such as speakers and printers.

The computer system **200** may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer **246**. The remote computer **246** may be a computer system, a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to the computer system **200**. The network connections include a local area network (LAN) **248** and a wide area network (WAN) **250**. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets, and the Internet.

When used in a LAN networking environment, the computer system **200** is connected to the local network **248** through a network interface or adapter **252**. When used in a WAN networking environment, the computer system **200** typically includes a modem **254** or other means for establishing communications over the wide area network **250**, such as the Internet. The modem **254**, which may be internal or external, is connected to the system bus **206** via the serial port interface **240**. In a networked environment, program modules depicted relative to the computer system **200**, or portions thereof, may be stored in the remote memory storage device. It will be appreciated that the network connections shown are exemplary, and other means of establishing a communication link between the computers may be used.

FIG. **3** illustrates a block diagram for a program module using OTL variables according to an embodiment of the present invention. For several examples discussed below, the structure of a programming module illustrated in FIG. **3** is utilized. In the example, a programming module **300** consists of a set of sections that include a header **301**, a variable declaration section **302**, a main procedure section **303**, and a methods and functions section **304**. The header section **301** may be used to provide needed declarations and metadata needed to specify the compile-time and run-time parameters of the programming module once an executable module is created from a source code file. The variable declaration section **302** allows for the declaration of any variables, especially secure variable that may utilize OTL libraries according to the present invention. The main procedure module **303** provides the set of instructions that are performed when the programming module is run. Within the main procedure module, various instructions **335**-**336** may reference variables declared in the variable declaration section. Finally, the methods and functions section **304** provides any additional set of functions and methods that may be utilized by the instructions within the main procedure module **303** as defined by a programmer.

FIG. **4** illustrates a block diagram for a program module using OTL variables calling procedures according to an embodiment of the present invention. As noted above, the example in FIG. **4** contains the four sections of a programming module discussed within FIG. **3** above. In this particular example, a set of three secure variables are declared in addition to any other declared variables. These secure variables include two secure integers, Secure_Int__1 **422** and Secure_Int__2 **423**, and a secure Boolean variable, Secure_ Boolean **424**. The OTL processing of this program module **300** will create a separate instance of a function that will obfuscate the contents of these secure variables. For any given type of variable, i.e., integer, float, character, Boolean, etc., a set of possible functions may be included within a library for use at compile time. Alternately, these functions may be generated on-the-fly during compile time.

In this example, each of the two secure integers will cause a separate instance of a function to be created. These functions may be entirely different operations to obfuscate an integer. For example, Secure_Int__1 may add a random offset to the run-time value of the variable where Secure_ Int__2 may XOR a random bit pattern with its runtime value. For both of these instances, a separate random value parameter may also be selected for each variable to further obfuscate the data contained therein.

The secure Boolean variable, Secure_Boolean **424**, may use an entirely different set of functions to obfuscate the contents of the variable as to prevent hackers from discovering its contents at runtime. One skilled in the art will recognize that any number of possible obfuscation functions may exist for use with various variable types without deviating from the spirit and scope of the present invention as recited in the attached claims. In addition, the complexity of the obfuscation function may be varied as a programmer decides how much effort should be applied to obfuscate a particular variable in light of the processing overhead that may be imposed with increasing complex obfuscation procedures. However, hackers may be hindered in their ability to decipher the operation of obfuscated variables since each secure variable is treated independently and may use different obfuscation functions and obfuscation parameters.

Within the main procedure section **303**, various instructions **435-438** will reference the secure variables **422-424** declared above. In one embodiment, these variables may utilize references to secure functions **441-443** to process the secure variables from a secure state to a plain text state for use in the main procedure section **303**. As discussed below, this embodiment may present needless creation of a plain text version of the secure variable that may be observed by hackers at run time.

FIG. **5** illustrates a block diagram for a program module using OTL variables in which OTL procedures are substituted into the programming module according to an embodiment of the present invention. Rather than utilizing the secure functions of FIG. **4**, another embodiment of the present invention will substitute the code for the secure function directly into the in-line code of the main procedure section **303**. For example, Secure_Int__1 **522** is referenced within Instruction 1 **531** and within Instruction m **561**. Similarly, Secure_Int__2 **523** is referenced within Instruction 10 **541** and Secure_Boolean **524** is referenced within Instruction n **551**.

When the source code is processed as part of a compilation of the processing module **300**, the secure variable declaration statements **522-524** will cause instances of the secure functions to be generated as discussed above. For each variable type, a particular instance of an obfuscation function is randomly selected or generated, as are any parameters utilized by the selected function. When the main procedure section **303** is processed, these instances of obfuscation functions are substituted into the particular instructions that reference a particular secure variable. For example, Both Instruction 1 **531** and Instruction m **561** contain a reference to Secure_Int__1 **522**. When these instructions are processed, the particular references to Secure_Int1 **532**, **562** are replaced with a copy of the instance of the obfuscation function **533**, **563** created for use in processing references to Secure_Int__1 **522**. Unlike the example in FIG. **4**, separate insertions of the in-line code for this obfuscation function are needed; however the in-line substitution will eliminate the call operation to the function itself to further obfuscate the variable to hackers. Similar substitutions of function code **543**, **553** are made for references **542**, **552** to other secure variables **523**, **524** used in the main procedure section **303**.

FIG. **6** illustrates a block diagram for a program module using OTL variables in which OTL procedures are substituted into the secure variable references according to an embodiment of the present invention. One possible additional advantage of using the substitution of code discussed above is that various operations to obfuscate contents of variables may be combined with other operations specified by a programmer. FIG. **6** illustrates an example of two such substitutions for secure integers X and Y in the source code **601** created by a programmer. In this example, the programmer specifies a test operation **611** on X>0 and specifies a similar operation **612** Y<0 in his or her code **601**. Within the two obfuscation functions specified in a particular instance of an OTL library **602**, X is defined as X minus a Random Number 1 **621**. Similarly, Y is defined in a particular instance **622** of the library as Y XOR Random Number 2. When these functions are substituted into the user's code **601**, the user specified instructions may be optimized in the form of X>Random Number 1 **631**. As such, the plain text version of X is never actually created in the runtime version of the code generated pursuant to the present invention. Thus, a hacker may never be in a position to decipher the value of X as well and its operation and use.

FIG. **7** illustrates a processing system for generating executable program modules using OTL modules according to one possible embodiment of the present invention. In a preferred embodiment, the OTL processing will be included within a compiler system **701**. This compiler system **701** accepts source code files **110** to generate executable files (e.g., EXEs and DLLs). The compiler system **701** includes a substitution module **711**, a compiler module **712**, a linker module **713** and possibly a set of additional obfuscation modules **714**. In addition, the substitution module uses an OTL selection module **722** and an OTL parameter module **723** that both utilize a type library database **721**.

The substitution module **711** generates the obfuscation function code for each declared secure variable using the OTL selection module **722** and the OTL parameter module **723**. The OTL selection module **722** selects or builds on-the-fly a particular obfuscation function for each declared secure variable based upon the type of secure variable and any input selection parameters. The OTL parameter module **723** generates any random parameters needed by the selected obfuscation function for each declared secure variable.

The compiler module **712** processes the source code following the OTL code substitution operation to generate object code that is combined with other executable modules by the linker module **713** to generate an executable processing module.

The set of additional obfuscation modules **714** implements additional obfuscation operations that may be utilized to make the operation of the processing module more secure. Past experience shows that attackers can often bypass the software protection mechanisms by snooping on the interaction between software and the underlying operating system. In particular, the arguments passed in Windows API calls are plaintext. An attacker has little difficulty intercepting API calls and changing their arguments arbitrarily. An obvious cure of this problem is to push data obfuscation deep into the OS. If the data is temporarily de-obfuscated right before its use—for example, an encrypted song is decrypted right before it's sent to the sound driver, or an encrypted file name is decrypted inside the file system module—the attacker will have much more difficulty in intercepting and modifying critical plaintext data.

No matter how much data obfuscation is put into a conventional PC operating system, it is still possible for attackers to reverse engineer the entire OS. Hardware-assisted secure PC is one way to forestall any software-based attacks. The Trusted Windows (TW) Initiative within Microsoft offers an excellent opportunity for data protection. On the TW platform, the trusted mini-OS is protected by hardware mechanisms that disallow any users from examining the memory content of the mini-OS and from debugging it by pure software means. Due to resource constraints and engineering complexity, the protection is limited only to the mini-OS; the bulk of the application software still runs in the untrusted domain. This problem can be alleviated by using OTL, as described in the following.

A TW application written with OTL is compiled into two components: the application binary and an OTL object decoder (OTL decoder) as shown in FIG. **8***a*. The OTL decoder contains necessary information for someone to de-obfuscate the OTL objects for this application. It is encrypted with the public key for the Trusted Windows PC that this application is licensed to. When the application is loaded on the TW PC, the corresponding OTL decoder is loaded into the mini-OS. All subsequent communication between the application and the mini-OS uses the OTL objects in their obfuscated form. We thus eliminate a common vulnerability present in current PC OS.

The use of OTL in securing API calls comes at no extra cost to the developers. All they need to do is to pass a SInt32 (or SBool, etc.) in the API call instead of int32 (or BOOL, etc.) The OTL decoder, to be run in the mini-OS, can be automatically generated by the OTL compiler middleware.

To protect data-access patterns in a program, we propose to inject auxiliary data and fake data accesses to both program data and auxiliary data. The injection is done by the OTL compiler. We partition the software into many code groups, each containing some global data, either OTL-based or non-OTL, shared among some groups. By inserting accesses to shared data and to auxiliary data in other code groups, artificial dependencies may be created among code groups. These extra data accesses are not to be deemed extraneous by simple data analysis tools. The result is a piece of software whose various components make seemingly random accesses to the heap. Furthermore, a traditional tree-like data dependency among the code groups may look like a complete graph as illustrated in FIG. **8***b*.

FIG. **9** illustrates a processing system for generating executable program modules using OTL modules according to another possible embodiment of the present invention. In a second embodiment, the OTL processing of the source code **110** occurs within a separate pre-pre-processing module **901** where the output of the pre-processor is passed into the compiler system **701**. In such an embodiment, the operations of the pre-processor **901** and the compiler **701** are identical to the processing discussed above; however the OTL pre-processor **901** may be used with existing compiler systems without requiring the modification of the compiler itself. Such an arrangement may require additional data storage as a new set of source code is created. However, the possible use of the OTL system with existing compilers may justify the added storage and overhead requirements of such an embodiment.

FIG. **10** illustrates an operational flow for generating executable program modules using OTL modules according to yet another example embodiment of the present invention. The processing begins **1001** and the input source code is processed by module **1011** to identify a secure variable declaration. Once a secure variable declaration is found, module **1012** queries an OTL database for possible OTL procedures for use an a instance of the variable. The query may return either a pre-stored procedure or one generated on the fly. The possible procedures returned by the query will depend upon the type of secure variable referenced in the declaration statement.

From the query results, module **1013** randomly selects or generates a single procedure for use in this particular instance of a declared secure variable. Module **1014** then creates an instance for this declared secure variable and defines any random parameters that may be needed by the procedure.

Test module **1015** determines if any additional secure variables exist within the source code. If additional secure variable declarations are found the processing returns to module **1011** to process the next secure variable declaration. If test module **1015** determines no additional secure variables are to be processed, the processing continues with module **1021** that locates the next reference to a declared secure variable in the source code.

When module **1021** finds a reference, module **1022** substitutes the previously created instance of the obfuscation function for the referenced secure variable into the source code. Test module **1023** determines if any additional secure variables references exist within the source code. If additional secure variable references are found the processing returns to module **1021** to process the next secure variable reference. If test module **10223** determines no additional secure variables references are to be processed, the processing continues with module **1024** to optimize, compile, link and further obfuscate the variables as discussed above. Once the executable processing module is created, the processing ends **1002**.

FIG. **2** illustrates an example of a suitable operating environment **200** in which the invention may be implemented. The operating environment is only one example of a suitable operating environment **200** and is not intended to suggest any limitation as to the scope of use or functionality of the invention. Other well known computing systems, environments, and/or configurations that may be suitable for use with the invention include, but are not limited to, personal computers, server computers, held-held or laptop devices, multiprocessor systems, microprocessor-based systems, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, and the like.

The invention may also be described in the general context of computer-executable instructions, such as program modules, executed by one or more computers or other devices. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Typically the functionality of the program modules may be combined or distributed as desired in various embodiments.

A computing system **200** typically includes at least some form of computer readable media. Computer readable media can be any available media that can be accessed by the system **200**. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. Computer storage media include volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media include, but are not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by the computer **200**.

Communication media typically embody computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism and include any information delivery media. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media. Combinations of any of the above should also be included within the scope of computer readable media.

While the above embodiments of the present invention describe a processing system for altering an image displayed to a user, one skilled in the art will recognize that the various computing architectures may be used to implement the present invention as recited within the attached claims. It is to be understood that other embodiments may be utilized and operational changes may be made without departing from the scope of the present invention.

The foregoing description of the exemplary embodiments of the invention has been presented for the purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not with this detailed description, but rather by the claims appended hereto. Thus the present invention is presently embodied as a method, apparatus, computer storage medium or propagated signal containing a computer program for providing a method, apparatus, and article of manufacture for providing secure and opaque type libraries to automatically provide secure variables within a programming module.

What is claimed is:

1. A system for providing secure and opaque type libraries to automatically provide secure variables within a programming module, the system comprising:

an OTL selection module, the OTL selection module randomly generating one of the possible variable obfuscation functions for each declared secure variable in a secure variable declaration statement of a source code module, the secure variable declaration statement comprising a variable type declaration for each declared secure variable;

an OTL substitution module, the OTL substitution module substituting a separate instance of a selected variable obfuscation function applicable for every reference to each declared secure variable;

an OTL type library database, the OTL type library database receiving queries from the OTL selection module and identifying possible variable obfuscation functions applicable for the variable type declaration corresponding to each declared secure variable;

a compiler module; and

a linker module to create an executable processing module.

2. The system according to claim **1**, wherein the system further comprises an additional obfuscation processing module to apply additional obfuscation operations to protect data-memory access patterns.

3. The system according to claim **2**, wherein the OTL substitution module optimizes the substituted variable obfuscation function with related instructions to further obfuscate the contents of the secure variable.

4. The system according to claim **1**, wherein the variable type declaration comprises secure integers, secure floating point variables, secure boolean variables, secure characters, secure strings, secure structures, and secure versions of all other data types.

5. The system according to claim **1**, wherein the OTL selection module randomly generates one of the possible variable obfuscation functions by randomly selecting a variable obfuscation function from a pre-defined library of functions.

6. The system according to claim **5**, wherein the OTL selection module, the OTL substitution module, and the OTL type library database are located in a pre-processor module.

7. The system according to claim **1**, wherein the OTL selection module randomly generates one of the possible variable obfuscation functions by randomly generating a variable obfuscation function using a pre-defined library of functions operators.

8. The system according to claim **1**, wherein each separate instance of the selected variable obfuscation function utilizes one or more parameters.

9. The system according to claim **8**, wherein the one or more parameters comprise randomly generated values.

10. A method for providing secure and opaque type libraries to automatically provide secure variables within a programming module, the method comprising:

identifying secure variable declaration statements within a source code module, each of the secure variable declaration statements comprising a declared secure variable and a variable type declaration;

querying a database for identification of possible variable obfuscation functions applicable for the variable type declaration corresponding to each of the secure variable declaration statements;

randomly generating one of the possible variable obfuscation functions returned in response to the database query;

creating a separate instance of a selected variable obfuscation function corresponding to each of the secure variable declaration statements; and

substituting the separate instance of the selected variable obfuscation function for every reference to each declared secure variable.

11. The method according to claim **10**, wherein the method further comprises optimizing the substituted variable obfuscation function with related instructions to further obfuscate the contents of the secure variable.

12. The method according to claim **11**, wherein the method further comprises: compiling the source code;

linking the source code with additional processing modules; and

applying additional obfuscation processing to protect data-memory access patterns.

13. The method according to claim **12**, wherein the method further comprises generation and injection of "useless" but potentially tightly integrated code designed to disguise the secure variable and deflect the attacker's attention away from sensitive data and code.

14. The method according to claim **10**, wherein the variable type declaration comprises secure integers, secure floating point variables, secure boolean variables, secure characters, secure strings, secure structures, and secure versions of all other data types.

15. The method according to claim **14**, wherein the secure Boolean variables correspond to time-varying secure Boolean variables.

16. The method according to claim **15**, wherein the time-varying secure Boolean variables are utilized to perform an authenticated function call.

17. The method according to claim **10**, wherein the separate instance of a variable obfuscation functions are selected, created, and substituted into the source code in a pre-processor module.

18. The method according to claim **10**, wherein the randomly generating one of the possible variable obfuscation functions randomly selects a variable obfuscation function from a pre-defined library of functions.

19. The method according to claim **10**, wherein the randomly generating one of the possible variable obfuscation functions randomly generates a variable obfuscation function using a pre-defined library of functions operators.

20. A computer program data product readable by a computing system and encoding instructions implementing a method for providing secure and opaque type libraries to automatically provide secure variables within a programming module, the method comprising:

identifying secure variable declaration statements within a source code module, each of the secure variable declaration statements comprising a declared secure variable and a variable type declaration;

querying a database for identification of possible variable obfuscation functions applicable for the variable type declaration corresponding to each of the secure variable declaration statements;

randomly selecting or generating on-the-fly one of the possible variable obfuscation functions returned in response to the database query;

creating a separate instance of a selected variable obfuscation function corresponding to each of the secure variable declaration statements; and

substituting the separate instance of the selected variable obfuscation function for every reference to each declared secure variable.

21. The computer program data product according to claim **20**, wherein the method further comprises optimizing the substituted variable obfuscation function with related instructions to further obfuscate the contents of the secure variable.

22. The computer program data product according to claim **21**, wherein the method further comprises:

compiling the source code;

linking the source code with additional processing modules; and

applying additional obfuscation processing to protect data-memory access patterns.

23. The computer program data product according to claim **22**, wherein the method further comprises generation and injection of "useless" but potentially tightly integrated code designed to disguise the secure variable and deflect the attacker's attention away from sensitive data and code.

24. The computer program data product according to claim **20**, wherein the variable type declaration comprises secure integers, secure floating point variables, secure boolean variables, secure characters, secure strings, secure structures, and secure versions of all other data types.

25. The computer program data product according to claim **24**, wherein the secure Boolean variables correspond to time-varying secure Boolean variables.

26. The computer program data product according to claim **25**, wherein the time-varying secure Boolean variables are utilized to perform an authenticated function call.

27. The computer program data product according to claim **20**, wherein the separate instance of a variable obfuscation functions are selected, created, and substituted into the source code in a pre-processor module.

28. The computer program data product according to claim **20**, wherein the computer program data product corresponds to a computer readable storage medium.

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